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SUPPORT OF IMAGING RADAR FOR THE SHUTTLE SYSTEM AND SUBSYSTEM DEFINITION STUDY

Phase II

California Institute of Technology
Jet Propulsion Laboratory

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PROGRESS REPORT RSC 3090-2

"Support of Imaging Radar for the Shuttle
System and Subsystem Definition Study"
Phase II

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1.0 Introduction

The Remote Sensing Center, Texas A&M University, is responsible for assisting the Jet Propulsion Laboratory (JPL) in establishing the demand for imaging radar data and providing guidelines for specifying the parameters of an imaging radar suitable for use in conjunction with the Space Shuttle. These broad objectives will be supported by Texas A&M University (TAMU) through a study consisting of three phases:

1) Survey of User Requirements
2) Determination of Radar Design Criteria Imposed by User Needs
3) Determination of Radar Specifications for User Applications.

Each of these phases are directly supportive of JPL efforts in response to their obligations to the NASA Johnson Space Center.

This progress report is concerned only with Phase II activities, however, Section 2.0 provides a general description of the complete project. The Phase I results were reported in Progress Report RSC 3090-1, July 15, 1974.

2.0 Project Description

The obligations of TAMU in each of the three phases of the project are described below.

2.1 Phase I: Survey of User Requirements

This phase includes establishing user agency requirements for radar imagery, evaluating the utility of imaging radar data in ongoing research and/or application projects, and conducting a preliminary examination of the feasibility of using existing imaging radar systems for specific user applications. TAMU will conduct interview sessions with user agencies to establish user agency requirements and priorities of radar imagery, and conduct a survey that will determine the organizations that are involved in ongoing application projects in which active microwave sensors would be of value.

2.2 Phase II: Radar Design Criteria Imposed by User Needs

Phase II has two main objectives. The first is to evaluate the applications of the user agencies to determine the radar system constraints imposed by each application area and group the applications according to commonality of system requirements. Secondly, TAMU is to establish general system criteria required by each of the user applications according to the previously determined application groups.

2.3 Phase III: Radar Specifications for User Applications

Candidate radar configurations are to be designated for the relevant application areas of the primary application groups. These configurations will include associated data handling requirements, and the principal trade-off parameters for each of the configurations will be indicated. Additionally, TAMU is responsible for preparing an illustrated presentation summarizing the findings of all three phases.

3.0 Active Microwave Remote Sensing

The major emphasis in the earth observations effort has been on visible-region sensors. This is true for both aircraft and satellite programs. Camera, vidicon, and multispectral scan systems have been employed extensively in the space program aboard Apollo, NIMBUS, ERTS, Skylab, among others, and similar systems are planned for future spacecraft, such as the EOS series. As a result of these and associated activities, such as development of large multispectral data processing centers, there exists a significant amount of empirical data and data analysis results supporting the application potential of visible-region sensors.

In comparison, the limited use of active microwave sensors has meant that an inadequate supply of usable empirical data exists, and hence, the application potential cannot be documented with similar confidence. The microwave remote sensing field does have the advantage of a far more extensive background in theoretical and analytical modeling studies, and many of the applications presented in this report are based upon these fundamental studies of the physical phenomena measurable in the microwave region.

The principal characteristics of active microwave sensors that are of primary interest to earth observations

are: a wide, almost unobstructed atmospheric "window" in the microwave region; an operating capability over more than a 100:1 wavelength range; control of the illumination source amplitude and direction; range and height measurement capability; capability of penetrating vegetation and near-surface materials; capability of producing image format data with fine resolution, independent of sensor altitude; and capability of recording unique descriptors of a wide variety of physical phenomena because of microwave signal dependence upon dielectric properties and surface texture.

The microwave remote sensing field is characterized by a strong reliance on theoretical studies and analytical modeling, in contrast to visible-region remote sensing which relies heavily upon empirical results. Analytical models for electromagnetic interaction mechanisms of interest to oceans and atmosphere remote sensing are well developed and have been verified with experimental results. Models descriptive of the mechanisms of concern in remote sensing of terrain are in various stages of development but generally lack adequate experimental verification.

3.1 Physical Phenomena Measured by Microwave Sensors

The information content of active microwave sensor data is contained in two aspects of the backscattered signal: 1) the magnitude of the radar return, and 2) the

spatial distribution of the elements of the illuminated scene. That is, the amplitude of the radar cross section is one information element, and the two-dimensional description (image) of the surface is another information element. For example, the determination of sea state using active microwave sensor techniques is based on the behavior of the measured radar scattering cross section; however, the mapping of geologic fault systems using active microwave sensor techniques is based primarily on the unique two-dimensional representation provided by these sensors.

These two information elements are seldom employed independently, especially in imaging applications, but since they represent two different classes of unique capabilities of active microwave sensors, they are presented here as distinct characteristics.

3.1.1 Scattering Cross Section

The radar scattering cross section is a measure of the "efficiency" of an illuminated area or volume to return the incident microwave energy to the radar antenna. The processes by which microwave energy is reradiated by a medium are often extremely complex, and may be significantly different for different applications depending upon the properties of the media being sensed. The following simplified discussion provides some insight into the various processes

influencing radar backscatter from terrain, oceans, and the atmosphere.

The most general case of microwave energy interaction with natural surfaces involves a rough surface layer, covered with a lossy dielectric medium (e.g., vegetation). There are three primary components present in the backscattered signal: (1) scattering and attenuation from within the lossy cover volume, (2) scattering from the rough surface boundary, and (3) scattering and attenuation from within the subsurface volume. Each of these components depend on the wavelength, polarization, and incident angle of the illuminating signal, and each are influenced by the electrical properties, composition, and texture of the various media involved.

In the specific case of active microwave remote sensing of oceans, the surface component is dominant, and the problem lends itself readily to analytical modeling methods. The primary parameter influencing the scattering cross section is the surface roughness. The objective is to determine the statistics of the sea surface by observing the behavior of the scattering cross section as a function of the system parameters, i.e., wavelength, polarization, and incident angle.

The wavelength of the microwave signal incident upon the sea surface acts in general as a "size filter"

responding to select ranges of scatterers according to their dimensions relative to the wavelength employed. Short wavelength energy is influenced more by small capillary waves and long wavelength energy is influenced more by large gravity waves. Variations in the scattering cross section, measured at any one wavelength as a function of the angle of incidence of the energy, correspond to the structure of the sea surface as defined by the distribution and orientation of responsive scatterers. For example, a "rough" sea surface composed of a large number of scattering elements may provide cross section measurements which are independent of the incident angle, whereas "smooth" sea surfaces provide cross section measurements with a pronounced angle dependence. This behavior characteristic is the basis for sea state determination using the Skylab EREP radar scatterometer.

An active microwave remote sensing situation where two of the three basic components in the backscatter cross section exist is that of sea ice detection. Microwave energy interaction with sea ice generates both a surface return and a subsurface volumetric scattering component. A similar situation exists in remote sensing of bare soils. The surface dependent backscattering component from sea is less than from water because the permittivity is less, hence the

reflection coefficient is less. As a result, more energy is transmitted into the subsurface medium where it experiences a volume scattering effect due to the inhomogeneous composition of the sea ice interior. This subsurface scattered energy is reradiated into the upper medium and becomes part of the total backscatter cross section measured for the sea ice.

The physical properties of the ice influencing the behavior of the subsurface component are different from those influencing the surface component. An example of the distinctiveness of these two processes is the significantly larger depolarization resulting from the subsurface volume scattering mechanism. As a result, different sea ice types have quite dissimilar effects on the incident microwave energy, hence, for example, multi-year ice is distinguishable from new ice when observed with microwave sensors.

The most complex, and least understood situation is when all three microwave backscatter components exist in the measured scattering cross section. This is the case for active microwave remote sensing of vegetated soils, for example. The surface and subsurface components are influenced in the same manner as described above, however, these mechanisms become effective only after the

microwave energy has penetrated the cover material. Vegetation can be represented as a lossy, porous, inhomogeneous dielectric medium which exhibits volume scattering and attenuation characteristics. Both properties are a function of the structure, density, and moisture content of the plant material. Most natural vegetation has a low volume of plant material and water per unit volume of canopy cover; less than 3 percent. Consequently, the attenuation of microwave energy passing through the medium is generally small, even for relatively short wavelength energy. However, short wavelength energy can excite appreciable scattering within the canopy volume which both adds a vegetation dependent backscatter component and reduces the energy incident upon the soil surface. Long wavelength microwave energy, e.g., 25 cm, is less susceptible to this volume scattering process, and therefore the soil surface and subsurface characteristics are far more influential than the canopy on the recorded backscatter cross section.

The processes involved in backscatter from a vegetation canopy are analogous to the processes of primary interest in some atmospheric measurements using active microwave remote sensing techniques. For example, the scattering of electromagnetic energy incident upon a

volume of raindrops is a volume scattering process which is highly dependent upon the wavelength of the incident energy. The size, distribution, and velocity of the raindrops each influences the behavior of the measured backscattering cross section. Like the case of vegetation, long wavelength signals can penetrate rain cells with little attenuation and/or scattering, whereas short wavelength signals may return a significant portion of this incident energy to the radar antenna.

It is the scattering cross section information which lends itself to theoretical studies and analytical modeling. This element of active microwave remote sensing information is generally recognized as the most unique and most significant feature of active microwave remote sensing for earth observations. However, the second element, i.e., two-dimensional representation, is the aspect of active microwave remote sensing most readily associated with ongoing activity in the remote sensing field because a radar image has photographic qualities and is amenable to photointerpretation techniques.

3.1.2 Two-Dimensional Representation

Although a radar image has photographic qualities, it has several unique characteristics which distinguish it from a photograph. The two most significant characteristics

of active microwave sensor images are: (1) the sensor provides an independent, controlled source of illumination, and (2) microwave wavelengths are sufficiently long that the scattering mechanism involved are not as diffuse as is generally the case with light. The first of these characteristics is the cause of the enhancement of surface features, for example. The second characteristic is the cause of enhancement of forward sloping terrain features, for example.

A radar image is, of course, in essence a two-dimensional display of the scattering cross sections described earlier, but it is more than that. It is a display of the spatial relationships characterizing the scene. More significantly, it is a unique geometrical representation of the surface features. Land rm features are enhanced due to radar shadowing, foreshortening, and layover; properties attributed to the independent illumination provided by active microwave sensors. Slopes are enhanced due to the incident and aspect angle dependence of the microwave energy. Surface textures are enhanced due to the surface roughness dependence of the monochromatic illumination. In summary, a radar image is a distinctive remote sensor product containing information supplementary to, but uniquely different from a photograph.

3.1.3 Wavelength and Penetration

Photographic sensors utilize a very narrow region of the electromagnetic spectrum. Using multispectral scanner techniques, such as the ERTS-1 MSS, a wavelength range of about 4:1 is available. By extending this approach to include the thermal infrared region, a range of as much as 50:1 is possible, however, many subregions within this range are closed due to atmospheric attenuation.

In the microwave region of the spectrum, an operating wavelength range of 100:1 is routine; a range of 1000:1 is practical; and a range of more than 10,000:1 is feasible.

This enormous operating region extends the range of physical phenomena that can be sensed. For example, at the short wavelength end of this range, atmospheric constituants such as water vapor and rain influence the microwave signal, and at the long wavelength end of this range, subsurface soil moisture influences the microwave signal. Within this broad range there exist regions of spectral reflectance response characteristics analogous to that giving rise to the concept of color in the visible region, hence, microwave "color" is a realistic, though untested, concept for active microwave remote sensing.

It has been mentioned that due to the wide range

of wavelengths available for microwave remote sensing, different properties of natural terrain can be identified with one multifrequency microwave sensor. For example, land use and vegetation species can be recorded using a relatively short wavelength; landforms and geomorphology can be recorded with a moderately long wavelength; and soil characteristics (under vegetation) can be recorded with a long wavelength. Consequently, a single system can obtain a far greater range of information than is obtainable with a single visible-region sensor and, of course, these data are obtainable day or night during nearly all weather conditions.

The capability of long wavelength signals to penetrate through various media has led to some misunderstanding about the ultimate utility of microwave sensors. Long wavelength "sounder" radar have been successfully used to record deep (more than 1 km) subsurface features on the Moon. In addition, special electromagnetic systems have been used on earth to locate deep copper deposits. However, in general, the capability of airborne or satellite active microwave remote sensors to explore beneath the surface of the earth is limited. The maximum practical wavelength operational from space is about 50 cm, because of ionospheric effects at longer wavelengths. Signals at

this wavelength will penetrate most natural terrain surfaces to a depth of less than one meter, and the return signal will represent an integration of the properties of the medium throughout this interaction region. Buried layers or objects beneath the surface have been detected by airborne active microwave sensors, but these instances represent special cases and cannot at this time be used to support a "deep" subsurface sensing application.

3.2 Role of Active Microwave Sensors in Earth Observations

Active microwave sensors can contribute significantly to earth observations because of the capability to perform one or more of the following functions:

- As *complementary* sensors providing an extension of the spectral description of the phenomena under study.
- As *supplementary* sensors providing an extension of the observation coverage of the phenomena under study.
- As *unique* sensors providing information on the phenomena under study which is unobtainable by any more practical means.

It is recognized that the unique capability of microwave sensors to provide data night or day during nearly all weather conditions is only significant if the data so obtained possess a quality and information content level adequate to supply the needs of the application. An

assessment of the relative strengths and weaknesses of active microwave sensor data indicates that satisfactory data are obtainable for several significant applications. In summary form, the strength and weaknesses of active microwave sensors are shown in Table 1.

TABLE 1

STRENGTHS AND WEAKNESSES OF ACTIVE MICROWAVE SENSOR DATA

Strengths

- Records otherwise unobservable phenomena.
  - Penetrates vegetation and near-surface material.
  - Surface composition and roughness dependent.
  - Sensitive to vegetation, soil, and snow moisture.
  - Controlled viewing angle for feature enhancement.
  - Provides broad spectral range information.
- Coincident capability with visible sensors for many applications.
  - Provides two-dimensional image data.
  - Broad areal coverage with moderate-to-high spatial resolution.
  - Records land use patterns and changes.
  - Computer compatible information.
  - Sensitive to vegetation type and condition.
- Capable of day-night, near all-weather operation.

Weaknesses

- Cannot record color-dependent phenomena.
- Data not spatially coincident with other sensors.
- Geostationary imaging operation not practical.

4.0 Imaging Radar Applications

4.1 General

This section provides a brief discussion of active microwave remote sensing as background to the primary objective of identifying specific applications of orbital imaging radar systems. The applications listed were obtained from the JPL User Meetings and the Active Microwave Workshop. For each application presented, radar provides either the most practical, the most advantageous, or the exclusive means of obtaining the needed information.

4.2 JPL User Meetings

On May 30-31, 1974, and August 19-21, 1974, JPL conducted User Meetings in an attempt to identify primary applications of imaging radar data as defined by representatives of recognized user agencies. A summary of the second of these meetings is included as Appendix A. A listing of the applications discussed in these meetings is shown in Table 2. This User Meeting listing is too general to support development of functional requirements for radar systems, but additional detail on each is available as a result of the Active Microwave Workshop.

TABLE 2

IMAGING RADAR APPLICATIONS

IDENTIFIED IN JPL USER MEETINGS

- Mineral exploration - Chevron
- Petroleum exploration - Chevron
- Coastal wave diffraction - Corps of Engineers
- Lake ice mapping - NASA/LaRC
- Landform identification and terrain analysis - USGS
- Soil moisture determination - USDA/ARS

4.3 Active Microwave Workshop

The attachment to Appendix A provides a summary of the results of the Active Microwave Workshop held in Houston, Texas, July 22-26, 1974. The applications identified for which imaging radar systems are appropriate are listed in Table 3. Much of the descriptive material included in this section is an adaptation of the Active Microwave Workshop Report edited by Rouse.

An examination of these applications shows that several require the use of radar operating in a mode analogous to photography, that is, a record of the "visible" surface is desired, e.g., an image of the surface vegetation for rangeland inventories. This type operation is referred to in the following as Radar-Photo Mode. A second class of applications requires a more sophisticated use of radar, that is, some feature such as vegetation penetration or surface roughness dependence is required, e.g., an image of surface materials and structures for petroleum and mineral exploration. This type operation is referred to in the following as Ramage Mode. Another class of applications requires complex modes of radar system operation, such as multifrequency or multipolarization, and these applications depend more strongly upon volume scattering effects than most other applications, e.g., images for soil moisture and

TABLE 3

IMAGING RADAR APPLICATIONS IDENTIFIED IN ACTIVE MICROWAVE WORKSHOP

- Lake ice monitoring
- Flood mapping
- Oil spill detection
- Landform identification and terrain analysis
- Crop identification
- Land use mapping
- Soil moisture determination
- Soil type mapping
- Petroleum exploration
- Rangeland inventories
- Mineral deposit mapping
- Coastal wetlands mapping
- Snow field mapping
- Global wave climatology
- Coastal wave diffraction
- Wave build-up in storm areas
- Monitoring of icebergs
- Observations of ship activities
- Polar sea ice cover mapping
- Precipitation intensity
- Liquid water content in atmosphere

snow field mapping. This type operation is referred to in the following as Special Mode.

It will be noted in the following that timeliness of observation is the most difficult parameter to satisfy in many application requirements. Radar has the unique capability to provide day/night, near all weather imaging, and this feature is stressed in almost all applications. However, in future operational situations, the orbit constraints will seriously limit the opportunity to capitalize on this radar feature. This problem is not a major concern for the Space Shuttle experiments and is not dealt with in detail in this report, but the eventual utility of systems tested on the Shuttle will be affected by the orbit constraints.

4.3.1 Applications Requiring the Radar-Photo Mode

Applications for which the Radar-Photo Mode is appropriate are:

- Lake ice monitoring
- Crop identification
- Land use mapping
- Rangeland assessment
- Iceberg charting
- Ship activity monitoring

In each case, a clear, undistorted image of the "visible" features of the illuminated scene is desired. A uniform, linear gray-scale is generally preferred, especially

for the first four applications listed. These applications acquire the largest multiple-look number of any of the three application classes. The area coverage of a single scene should be as large as practical, i.e., maximum attainable swath width. These applications call for short wavelength, high resolution performance, and monochromatic, single polarization operation is usually adequate. The incident angles and aspect angles employed are not as critical as applications requiring the Ramage Mode, for example, but incident angles near the vertical or near grazing are unsatisfactory.

4.3.1.1 Lake Ice Monitoring

The basic objective in lake ice monitoring is to determine the spatial and temporal distribution of ice and snow cover in terms of mass concentration, i.e., volume of ice in a specified area. This information is extremely important to ship transport in the Great Lakes.

In the study of seasonal lake ice, the day to day changes in the structure and distribution of snow on the surface of the ice sheet affect the structure of the ice sheet. Newly fallen snow and the drifting of this snow around and in the lee of obstacles on the ice sheet is, if sufficiently thick, capable of producing a significant insulative cover on the ice and thus retard ice growth

(Billello, 1968). In addition, when snow fall is small, ice growth is greater, assuming that other climatology and limnology parameters are constant. There is also the possibility that, on a sheet of thin lake ice, the snowfall may be sufficiently great to exceed the bearing strength of the ice, causing it to crack. Cracks may also be caused by thermal expansion and contraction (Wilson, _et al._, 1954). Water, infiltrating through such a crack may mix with and saturate the overlying snow, forming a slush layer which, upon freezing, forms a highly granular ice layer, referred to as "snow ice" or "white ice". This type of ice is uniquely identifiable on SLAR imagery (Bryan, 1973).

Another commonly identifiable feature is called an ice-foot. An ice-foot is described as being composed of any combination of frozen spray or lake water, snow accumulations, brash, stranded ice floes, and sand which is either thrown up on the ice by wave action or is blown out from the exposed beaches. Although they are localized features, in that they occur only on shorelines of relatively large lakes, they are important indicators of geomorphic activity along the shoreline. They often persist into the spring after much of the lake ice has been melted or blown into the lake, and thus act as breakwaters,

protecting the shoreline from erosion and deposition. They can, if not removed from the shoreline, present a hazard to navigation in a manner similar to icebergs in the North Atlantic. Several recent papers have described these ice foots (Bryan and Marcus, 1972; Marsh, Marsh and Dozier, 1972; Evenson, 1973; Fahnestock, et al., 1972), which are clearly visible on SLAR imagery.

Interpretation of radar data on lake ice are available (e.g., Waite and MacDonald, 1970; Larrowe, 1971; Larrowe, et al., 1971), but generally these have been of a qualitative, not a quantitative, nature. Larrowe interpreted images by comparing air photographs taken simultaneously with the radar imagery (X-band, HH Polarization). In all of the above studies, the lack of ground truth seriously limited any real study of the radar imagery as to the ice structure and thickness, crystal orientation, pressure and thrust features, cracking, and similar features.

4.3.1.2 Crop Identification and Rangeland Assessment

Crop identification represents the first step in agricultural remote sensing. Success in this task, therefore, is potentially useful to the entire agricultural community. Government agencies like the Statistical Reporting Service (SRS), Foreign Agricultural Service (FAS), and Economic Research Service (ERS), are perhaps the primary

users along with particular commodity groups like the National Association of Wheat Growers. Tax assessing boards at the state and local level have a vested interest in accurate crop identification for tax purposes. Others are concerned for reasons of projecting water use and allocation.

Assessment of crop condition is immediately useful at local levels of agriculture and all of its supporting agri-business; consequently, it is believed that the "grass roots" farm and farm support community comprises the bulk of the users. Insofar as crop condition impinges on yield and productivity, users already cited above should also be included.

Utilization and management of the nation's rangeland by the individual owners and operators involved management decisions on a day-to-day basis. These decisions involve determination of optimum grazing density, regional animal movement, grain feed demand, spraying to prevent encroachment, and decisions brought about by the impact of regional drought. Estimates of quality and quantity of a range, on a regional basis, available to the cattleman affect decisions involving relocation of animals, natural grazing versus feedlot operations, and marketing practices. In the six Great Plains states extending from Texas to

North Dakota, there are approximately 400,000 independent ranchers and farmers concerned with rangeland conditions. These six states produce 40 percent of the nation's beef. The beef industry in this region exceeds 10 billion dollars annually, but despite this fact, it is inadequately provided with regional range condition information. The Weekly Weather and Crop Bulletin provides a gross range condition map derived from reports from county agents, however, these data are inadequate to support effective management practices on a regional basis.

There have been several published examples illustrating the capability of radar to differentiate both cultural and natural vegetation classes (Haralick, et al., 1970; Morain and Simonett, 1966; Morain, 1974; and others). For agriculture, specifically, the feasibility for identifying crops has been shown for a combination of Ka-, Ku-, and X-band imagery.

From the above efforts have arisen the basic justification for current ground-based microwave research in agriculture experiments by deLoor and Jurriens (1971) and Ulaby (1974), among others. These experiments are extending the knowledge of signal interactions with crops and soils under differing cover, moisture and plant morphology conditions. Generally, increase in plant cover is

associated with increasing scene moisture, hence the microwave response also increases. As crops decline in leaf area, dry out, or are harvested, signal strength drops. These cyclical trends can be useful not only to crop identification, but, when viewed under anomalous circumstances, might also aid as stress indicators.

For a large area inventory of a single crop where its identification can be achieved on the basis of its unique phenology (e.g., winter wheat) or environmental conditions (e.g., flooded rice), active microwave sensing may not require the level of research effort alluded to above. For example, a survey of winter wheat acreage was performed for Finney Co., Kansas, using Ku-band imagery. The results indicate the feasibility for accurately tabulating acreage for this particular crop. Once the acreage is determined, the application of an appropriate yield model permits the calculation of total production for a given area.

Relative to the inventory of natural vegetation, Morain and Simonett (1967) investigated methods for the interpretation of vegetation from radar imagery through use of an image discrimination, enhancement, combination and sampling system (IDECS) developed at the University of Kansas. The study dealt with various color combinations

possible with HH and HV polarization K-band imagery on which various forms of level slicing and data-space sampling were performed. In this study, probability density functions confirmed that data-space sampling on a single image, or in two-space on two images coupled with color combinations, is a valid discriminatory tool in studying natural plant communities.

4.3.1.3 Land Use Mapping

In recent years, it has become clear that effective state, regional, and national land use planning requires the bringing together of a wide range of areal data. These include data on static components of the environment, including soils, slope, geology, hydrologic systems; and on dynamic cultural land use and related components, including transportation routes, urban and rural land use, and public intrastructure. It is in the interplay of these natural and cultural features--the one relatively static, the other to a greater or lesser degree dynamic--that planning takes place. Monitoring of change in land use is thus of value not merely in itself, but also for its interaction with other land uses and with the background environment. It is in the area of monitoring land use change, especially the more dynamic components, and the interaction between land use and dynamic features

of the environment (floods, hurricanes, etc.) that the principal focus of this application lies for radar applications and land use analysis.

Though the relations between land use and environmental quality are ill-defined and do not lend themselves to orderly or simple analysis (Simonett, et al., 1973), general public awareness has increased about these relations, and has helped focus attention on land use planning and management as one means of achieving a reasonable balance between economic well-being and environmental quality.

Traditionally, the bulk of the U.S. land use data have been for counties and various metropolitan planning agencies. Counties have only rarely been of sufficient size or commanded sufficient capital to engage in regular land use inventory as part of their planning function. Yet counties have been the principal arena for interplay between the public and private sector when zoning and development are brought into conflict. Small, undercapitalized planning departments have been no match for private interests, and zoning decisions frequently stand only so long as the more powerful private interests are not engaged. While the balance between public and private interests as represented by metropolitan planning agencies

and councils and private developers has perhaps been more even than at the county level, there are numberless examples of the protagonists of "the highest and best use", in a strictly economic sense, ignoring environmental and neighborhood quality considerations.

These facts have stimulated the intense national and state-level interest in land use inventory, monitoring and planning. The Federal initiatives in this area all focus on stimulating state level activity. Thus, the natural interests of the state, reflecting citizen concern for a more forceful public voice, and the Federal pressures for state action have converged in making the state, and in some areas and for some problems, regional groups of states, the prime focus of the current trends in land use planning.

While these trends and pressures have by no means run their course, there is every reason to believe that by the time spacecraft active microwave systems have the opportunity to be employed in land use planning, a wider and stronger role for the state will have developed. In similar fashion, state-sized areas, and regional groups of states concerned with common environmental problems, (for example, Rocky Mountain States, and Northern Plains States concerned with strip mining, and oil shale development) also

will have developed and strengthened.

The principal interests of the states are converging on the development of statewide geobase information systems as part of the planning base, and on the possible future integration of economic modeling and forecasting through employment of the geobase data on natural and human resources on a small-area basis. The ability to overlay and examine spatially finely disaggregated economic and census data (at the census tract level), land use, and static and dynamic environmental background data together is now seen as a major area for state agency planning and development. The State Department of Planning in Maryland is already moving along this route.

The many regulatory and monitoring requirements in existing and planned federal and state legislation will hasten the process and offer opportunities for remote sensing of land use, change in land use, environmental stress, and illegal or undesirable actions in the private sector.

In addition to these environmental and land use monitoring concerns, both federal and state agencies and private corporations and relief agencies have shown increasing interest in planning for natural disasters. This interest finds expression in concern with insurance programs,

disaster relief, damage area and damage value assessment during and following the event, population re-settlement and related matters.

A number of states and federal agencies realize that detailed land use information coupled with data on the extent of the disaster in relation to various land uses, is one of the most effective ways of obtaining perspective on the scope and intensity of a disaster and thereby the conditions in part dictating the response.

Detailed land use data by area will serve to assess the number of lives and property value at risk. In flood plain land use as an example, the critical method for assessment during a flood is the interaction between the extent, depth and persistence of flood waters and the effects by class of land use of such extents, depths and persistences. Studies are only now beginning, but will be of increasing importance as state developed information systems begin storage of land use, census and relevant socio-economic data by city block and census tract.

Certainly one of the widely anticipated advantages of a statewide geobase information system lies in its ability to provide data rapidly in disaster situations, and such refinements as anticipatory planning for river flood and coastal area damage through storage of high density

data may be expected to become commonplace.

Both of the concerns mentioned (land use planning and disaster monitoring) are directly relevant to active microwave remote sensing. Indeed, for disaster monitoring, active microwave sensing is obligatory, since they are the only sensors which can obtain data on demand. It therefore must be the prime sensor for a disaster monitoring system designed to obtain data on the extent and progress of riverine floods, hurricanes, great fires, tidal waves, volcanic eruptions, earthquakes, landslides, and blizzards. Data on these events must be obtained at night, through clouds, rain, smoke, dust, fog and smog. Only imaging radar meets these requirements.

In a less urgent vein, active microwave systems appear as sensors of at least equal rank with visible-region sensors in a general program of land use monitoring, up-dating, and regulatory management. The roles for active microwave remote sensing may be summarized as follows:

- They will provide data in areas partially obscured by clouds and through cross calibration with visible region sensors, may be used for partial extrapolation at a single time.
- By assuring systematic, orderly acquisition of data, they will enable monitoring systems to

be set up in which continuity of data acquisition is of the essence. Such situations will occur where regulatory matters are involved, and where progressive change is a key element in land use analysis. This role may be described as the provision of key time data, in which active microwave remote sensing is essential for the effective functioning of the monitoring system. Certainty of data acquisition will in many cases be the deciding factor in decisions to initiate a satellite remote sensing monitoring system in the first place. Just as a manufacturing plant at the mercy of irregular supplies of key materials incurs high costs and may be forced to operate below peak efficiency, so too will an information system subject to sporadic arrivals of data, long time gaps, partial data at a single time and similar problems, be forced to operate at low efficiency or even to go out of business. In parts of persistent cloud cover, such as parts of Western Europe, Wet Tropics, Northwest U.S.A., and of rain and fog, or in high latitude during winter, active microwave systems will be

the only sensors on which a rational program can be built. For such areas, active microwave is an obligatory sensor.

- In land use (including agricultural areas) data acquisition programs employing multi-stage sample designs, it is commonplace to find that these designs are not robust in the face of missing data. The role for active microwave sensors may be to provide key-complement information.

If imaging radar systems are provided to meet the short term data gathering needs outlined above for disaster monitoring (2 hours to 10 days) and for mid-term land use monitoring, updating and regulatory management (11 to 100 days) the opportunity will also rise to use active micro-wave sensors for other, less time-dependent, but system-essential roles. These additional roles involve mainly once-a-year surveillance at a key time of the year. These long term monitoring programs (100 days plus) though required only infrequently, nevertheless may still have critical time-dependent features which restrict the period of data acquisition. The first two areas must bear the burden of proof of the utility of active microwave sensors. Once the decision is made to employ them, however, a raft

of secondary opportunities in land use will follow, principally of the long term monitoring type providing back up to visible-region sensors.

4.3.1.4 Icebergs and Ship Activity Monitoring

Although charting of icebergs and monitoring of ship activities are not necessary related applications, the radar system parameters for each are identical. The detectability of icebergs is improved by optimizing the observation wavelength, but like ships, they are so readily visible at all practical microwave frequencies that this parameter is not critical.

The need to improve the periodicity and accuracy of iceberg charts in support of ship routing in the north Atlantic is important to personnel and cargo safety and vessel crossing times. Reconnaissance of ship activities, especially in coastal regions is of ever increasing importance due to the steady increase of international shipping and the advent of the super tankers and their off-shore docking facilities.

4.3.2 Applications Requiring the Ramage Mode

The applications classified under this heading require image data containing more information than just a record of the "visible" features of the scene. Some unique

characteristic of microwave remote sensing must be employed to satisfy the information requirements. Rouse (1971) coined the word RAMAGE (pronounced: $r\bar{a}$'måj) to describe this image product uniquely obtainable by imaging radar systems. Applications for which the Ramage Mode is appropriate are:

- Flood mapping
- Coastal wetlands mapping
- Soil type monitoring
- Landform identification and terrain analysis
- Petroleum exploration
- Mineral deposit mapping
- Oil spill detection
- Global wave climatology
- Coastal wave diffraction
- Wave build-up in storm areas

In each case, the physical phenomena to be measured in support of the application requires a unique characteristic of the microwave signal. This may be either vegetation penetration, surface roughness or structure dependence, or radar shadowing. The desired image is distinctly different from a photograph. For these applications, the radar parameters such as wavelength, incident angle, etc., are more critical and often more complex for those applications using the Radar-Photo Mode.

4.3.2.1 Flood Mapping and Coastal Wetlands Mapping

Mapping of flood zones and coastal wetlands are similar from the viewpoint of utilizing radar imagery in

that the microwave interaction phenomena that provides the desired information in the radar image are the same in each application. In each of these applications, the ability of microwave energy to penetrate vegetation and the large contrast in signal returned from land and water are the primary phenomena utilized.

The coastal zone is a highly variable, dynamic, and complex region. The usefulness of the coastal zone is attested to by high land values and population densities. Pressures are being exerted on the land, water, and air by those who wish to use the region for recreational, industrial, and commercial development. Not enough is known of the coastal zone to properly evaluate these uses.

Coastal geomorphologists are interested in coastal zones which are frequently cloud obscured. Imaging radar provides a continuous image strip exhibiting a high contrast coastline. Because coastal change is often greatest during the height of a storm (El-Ashry and Wanless, 1967), the near all weather-ability of microwave systems should provide data that would aid in better understanding the process of coastal erosion.

Coastal maps have been up-dated using radar (MacDonald, Lewis, and Wing, 1971). In addition, a variety of coastal zone features have been mapped in Panama and

Colombia by Lewis, (1971), Lewis and MacDonald, (1970), Lewis and MacDonald (1972), MacDonald, Lewis, and Wing (1971). Most of these features were mapped for the first time and, as a consequence, provided information on the tidal influence, wave energy, and climate not previously known (Lewis, 1971).

The detection of tidal zone features such as mud flats and shell reefs, and the surf zone has subsequently been found to be strongly affected by position in the range. Similar to the detection of lakes, the above features are better detected in the near range (Hanson and Dellwig, 1973).

Cultural features unique to coastal/wetland environments are also evident on radar imagery. These include marsh buggy tracks, access canals and pipelines, offshore oil platforms, ships and accompanying wakes, jetties, groynes, piers, and buoys. The effect of groynes can be monitored by noting the deposition on the up-current side of the groyne.

The general objectives of flood mapping are to study the extent, duration and seasonality of flooding in both rural and urban settings. Data concerning the extent and duration are needed in "real time", whereas seasonality requires long term, repetitive coverage over several years. Ground cover analysis is viewed by many as an approach to determine infrequent or singular floods (e.g., 100 year

floods). A program of flood mapping would provide additional remote sensing data for delineating floodplains, and thus, be a primary benefit to land use planning authorities.

Major flooding originates in a drainage basin, generating a pulse of water that eventually reaches a major tributary moving downstream. Flood crest at a given point may occur during non-daylight hours or at times when photographic sensing is not possible. Real time knowledge of the extent of local inundation is vital for improving civil defense procedure. In a less real time context, data could be used for flood plain management.

Active microwave sensors could significantly enhance real time data acquisition. In addition, active microwave sensors should provide an excellent flood inundation mapping tool because of the high moisture dependence of the electrical properties (e.g., dielectric constant) of the soils. Some wavelength radar systems capable of reasonable penetration into the soil (5-20 cm) have been used to map changes in near surface soil moisture for bare soils. Operation of wavelengths in the 20-30 cm range appear to enable soil moisture monitoring even under vegetative canopies (Rouse, 1974).

4.3.2.2 Soil Type Mapping

Although aerial photographs have become a standard

tool in national soil surveys, little use has been made of radar imagery in soil surveys. This situation is the result of a number of factors, but a major restriction on the use of radar imagery is a present inability to interpret the radar image. The success of aerial photography for soil survey has been built upon an ability to relate soil patterns, usually not actually visible on the imagery, with the distribution of other landscape features, which are visible on the imagery. Radar studies have so far lacked the dual understanding of image pattern and soil distribution that has been essential in the use of aerial photography. This limitation is largely the result of a tendency to regard the radar image simply as a photograph, thus ignoring its special characteristics.

Previous research on radar reflectance from soils has used one of two approaches. First is laboratory research such as that conducted by Lundien (1966, 1971), who measured radar reflectance from artificially structured soils at several texture and moisture conditions. A second approach, used by Sheridan (1966), Simonett (1968), and Barr and Miles (1970), applied photo interpretation procedures to radar imagery to demonstrate that natural soil distributions in the field correspond, in some areas and under certain conditions, to patterns observed on radar

imagery. Their interpretations, however, largely ignore the differences between radar and photography, and present strictly empirical interpretations, without explanation of the soil properties recorded on the imagery.

Dielectric properties of soil are directly related to water content (Lundien, 1971). The nature of the relationship has been empirically derived by Lundien (1966) for Richfield Silt Loam at four radar frequencies. For all frequencies measured, the dielectric constant increased with increasing moisture. In a similar manner, for any two soils having nearly the same characteristics of particle size, shape, and arrangement (together with pore size, shape, and arrangement), the soil with the higher water content should have the higher dielectric constant, and appear in relatively light tones on imagery. The relationship is such that one would expect a small increase in soil moisture near wilting capacity to result in a significant increase in radar reflectivity and, hence, image tone. Addition of moisture to an already moist soil, however, should not significantly alter its already high reflection.

Relationships between wavelength and soil texture have been developed. The radar wavelength for "rough" (2λ) and "smooth" ($\lambda/10$) surfaces for midpoints in the

bandwidths of V, K, X, and L-bands have been matched with USDA soil texture classes. These relationships are expectations based on theory. In practice, identification of surface materials is much less precise because of the variable importance of moisture content and vegetal cover. Nevertheless, Sheridan (1966) has verified from field examinations near Bishop, California that on Ka-band imagery, gravelly soils image in comparatively light gray tones while silty and clayey soils appear in darker tones. His observations were made over an incident angle range from 30-65°. Morain and Campbell (1974) believe that arid lands offer the best opportunity for surface material identification because there is little surface moisture or dense vegetation to complicate the situation.

4.3.2.3 Landform Identification and Terrain Analysis

Landform identification and terrain analysis (geomorphology) is a discipline that has applications in geologic exploration, civil engineering, soil mapping, land use planning, and water resources management. The geomorphology section has been placed in the geologic exploration because of (1) the profound application of landform analysis to oil and mineral exploration; and (2) the natural/historical relationship of geology/geomorphology.

Most geomorphologists are interested in describing or identifying landform features or regions and understanding the processes responsible for shaping the landscape. This can be approached qualitatively or quantitatively. Radar imagery is extremely helpful in either approach. Qualitatively, radar imagery can be used for regionalization of landform units as well as for identifying individual landform features. Quantitative landform data, relative relief and slope, can also be determined using inherent radar distortions, radar foreshortening, shadowing and, to a lesser degree, layover and parallax.

<u>Regional Geomorphology</u> - The texture, pattern, and shapes of the radar shadows resemble a typical Raisz diagram of the region and allows the delineation of discrete landform units accurately and easily. Landform units mapped on radar have been found to agree well with units derived from topographic maps (Schwarz and Mower, 1969; Lewis, 1971). In fact, along a proposed sea-level canal route in Panama, the agreement between map-derived and radar-derived units was remarkable. When only three landform units (plains, hills, and mountains) were compared, over 90% agreement was found in all cases.

Exploration geologists have used the same surface expression so evident on radar imagery for the location of

possible mining sites. Bauxite deposits have been discovered in Brazil by correlating terrace units having known bauxite deposits with previously unmapped terraces delineated on radar images. Other lithologic units show considerable surface expression characteristics and can therefore be mapped as geomorphic units.

Individual Features - Many geomorphic features are detectable on radar imagery. Some of these are of interest to exploration geologists, as for example ring dikes, plugs, faults, fractures, colderas, shell bars, estaurine meanders, and drainage patterns. Evidence of glaciation (McCauley, 1972), stream piracy (Peterson, 1969), coastal erosion and deposition (Lewis, 1971), and karst topography (MacDonald, 1969), have also been reported.

Quantitative Geomorphology - The accurate description of landforms is the first step in any geomorphic study. The three most important vertical dimensions used in landform analysis are elevation, relative relief, and slope. Of the three, slope is most widely used. By utilizing inherent distortions of radar imagery, such as radar foreshortening, parallax, layover, and radar shadowing, relative relief and slope data can be collected.

Although active microwave sensing can in some cases be used to determine individual slope values, its

real value focuses on the determination of slope angle distribution on a regional scale. Radar foreshortening (Dalke and McCoy, 1969), radar shadows (Lewis and Waite, 1971) and radar power return (Lewis, 1971) have all been evaluated as a source of slope data by comparing the radar-derived data with map-derived data. The studies referenced here met with varying success, although radar layover and parallax are in part slope dependent and therefore are a potential source of morphometric data. The difficulty of accurately measuring layover and parallax on radar imagery is a severe limitation to its use.

The most practical source of morphometric data is radar shadowing. Although radar-derived slope data can be obtained for all types of terrain, shadowing is most prominent. Radar foreshortening is most practical in moderate and low slope regions. Foreshortening is limited however by the extremely fine accuracy required by the foreshortening equation (Lewis, 1971).

The use of radar power return as measured from radar image tone was tested as a source of slope data and met with little success. Although there is a linear correlation between radar tone and power return (Cosgriff, Peake, and Taylor, 1969), the assumption that vegetation remains constant is impractical. The utilization of radar

scatterometry and/or interferometry data however, would eliminate the problem and presumably make the measuring of terrain slope from power return of interferometry a viable application.

The determination of relative relief is a logical extension of any slope measuring method that requires the slope length as a known parameter, namely, radar foreshortening and radar layover. However, radar shadows can be used to measure relative relief, by measuring shadow length instead of frequency. Of all the methods evaluated, shadow length was the most accurate, having correlation coefficient values (r) of 0.86, when compared with map-derived regional values.

Geomorphic Summary - The qualitative regionalization of landform regions and subsequent measuring of regional and individual morphometric parameters is of special value to the environmental geologist-physical geographer as it provides insight into landscape dissection, terrain surface roughness, and terrain mobility. The exploration geologist should be able to relate landform morphometric data to stratigraphic and lithologic units and to regional anomalies.

4.3.2.4 Petroleum Exploration and Mineral Deposit Mapping

Radar imagery provides a useful informative base on which to plan specific ground programs for mineral and

oil exploration. In using radar imagery, the interpreter relies strongly on trends that are apparent at the surface, such as type, thickness, and attitude of formations, and fault traces and their disposition. The interpreter also makes use of associative clues indicating structure and lithology as well as stream patterns and vegetation. Areas having indicators of potential mineral and oil exploration sites may now be more confidently defined using radar imagery.

The common surface indicators signaling mineralization to the radar interpreter include fracture zones, veins, and rock type association. The sites of igneous plugs, or volcanic centers in general, are highly prospective for metal mineralization (e.g., sulfide veins), especially if associated with fractures having obvious tensional orientations. The margins of discrete igneous intrusive bodies such as stocks, are similarly prospective, the more so where fault swarms, radial faults, or other tensional fractures coincide. A detailed geologic study using radar imagery of eastern Panama has highlighted potential mineralized areas based on most of the above stated criteria (Wing, 1971). Wing also documented the utility of radar imagery for inferring the location of placer deposits, and based on the work of MacDonald and Waite

(1973), it seems feasible to identify and map sand and gravel deposits, which are critical to the construction industry.

Several other radar exploration programs oriented at minerals have been completed in the tropics. For example, in November 1971, Westinghouse undertook a SLAR survey of the entire country of Nicaragua for the Nicaraguan Government. The 1:250,000 scale imagery so obtained was compiled into 1:100,000 and 1:500,000 scale mosaic series by Hunting Geology and Geophysics, Ltd., which also interpreted the imagery for approximately two-thirds (80,000 sq. km) of the country. The interpretations aimed at topography, geomorphology land use, vegetation and geology overlays for the 1:100,000 scale radar mosaics. It was concluded from this Nicaraguan study that potential exists for forestry, livestock, and general agriculture, and that selected areas urgently deserve systematic search for mineralization.

During the fall of 1972, President Rafael Caldera of Venezuela announced a new mineral find "of great importance," including iron and possibly uranium, as a result of radar mapping in the south of Venezuela. The SLAR used was the Goodyear system.

The imagery itself does not show mineral deposits but indicates to geologists where ground surveys should be made. The find, named Cerro Impacto, contains a complex combination of minerals of great commercial and strategic value including a high content of iron, manganese, thorium, niobium and radioactive materials.

Many radar mapping programs have been conducted by petroleum companies; however, because of the proprietary nature of this information, published reports are not available. The only published report dealing specifically with radar mapping and petroleum exploration was completed in eastern Panama and northwestern Colombia by Wing and MacDonald (1973). These authors concluded: "With the exception of those data provided by field investigation, the geologic information interpretable from the radar imagery of eastern Panama far exceeds those data previously available through conventional airborne reconnaissance methods. Certainly, radar remote sensing offers the only practical technique for reconnaissance mapping in the wet tropics; however, even where conventional aerial photographic coverage can be obtained, radar imagery can be a valuable supplement because of its unique data content. Radar geologic reconnaissance--preferably with, but even without, air-photo support, can serve the petroleum geologist

as an important tool because of its substantial physiographic-geologic data content."

4.3.2.5 Oil Spill Detection

Oil pollution constitutes a major threat to U.S. water resources, marine life, waterfront property value, and the recreational industry. Oil pollution incidents are generally agreed to be a diıect result of the

- number of transfer operations between vessels and shore facilities.
- volume of oil transferred.
- number and length of vessel passages within U.S. waters, and number of off-shore oil wells.

The size of the area to be covered is significant. It includes thousands of miles of rivers, lakes, harbors, and coastlines. Remote sensing techniques which enhance the ability to observe oil discharge will materially assist in the enforcement of applicable laws and tend to ameliorate the environmental damages thro ›re rapid response and clean up.

Because of the damping effect of oils on capillary wave structure, oil spill⁼, both natural and man-caused, should be visible on imaging radar pictures. For example, it should be possible to assay the existing amount of surface oil cover in a region such as the eastern Gulf of Mexico,

which is soon to be opened up for oil exploration and drilling, and once in possession of these baseline data, determine if significant increases in that coverage have occurred as a result of the drilling operations. Furthermore, the drift of oil spills under the influence of currents and winds may be observed, especially in bad weather.

4.3.2.6 Wave Climatology

Any dynamic phenomena on the ocean surface such as ship motion and forces on anchored or stationary platforms are governed by the actual and/or expected sea state. Since the ocean surface is random, the only way to define it is by statistical description. The usual method used to describe wave motion is by the wave number or wave frequency spectrum and how this spectrum is expected to vary under different conditions. Therefore, models to predict the expected wave spectra for given geographical and meteorological conditions have received much attention.

It is known that the primary mechanism by which waves are generated is the surface wind. Moreover, in the open ocean (i.e., without boundaries) with no currents, the wind uniquely determines the wave spectrum. However, the relationship between wind conditions and the sea state is still not completely resolved. Moreover, when boundaries

or currents are present, it becomes increasingly difficult to predict the wave statistics.

Due to the inability to uniquely predict the wave spectrum. the approach must be to measure the wave spectrum, or wave statistics, in order that mathematical models may be refined by observations and thus yield the desired data. The measurements must be made on a global scale, as some of the factors (e.g., storms, geostrophic currents, etc.) which affect the spectrum extend for hundreds of miles. Because of these large scale processes that influence the sea state, measurements at a single point or several points at different times are difficult to interpret. Therefore, remote sensing offers a great many advantages in developing global wave statistics. Such statistics have two immediate and widely useful purposes:

1. To establish reference conditions to be used for design and planning and to evaluate global wave models.

2. To monitor any changes from the reference condition. Such changes could be caused by storms, currents, topography, pollution, etc., and the change in wave spectra can be used to evaluate the size and nature of these phenomena.

Predictions of wave spectra are presently based on local conditions, generally obtained from ships primarily because this is all the information that is available.

However, it is known that very large scale phenomena (storms, global currents, etc.) alter or determine the wave spectrum. For this reason recourse must be continually made to observations of measured wave characteristics typical of that given by Hogben and Lumb (1967). Moreover, in coastal regions, the open ocean waves must be considered in combination with local topography to develop realistic estimates of the wave spectra.

It is possible that if global meteorological data were available, more accurate models for prediction of wave spectra could be developed. Such models would need to be verified by global wave statistics, however. Therefore, remote sensing appears to not only offer the opportunity to evaluate and improve wave spectra but to be the only way presently available to do so.

The capability for global monitoring of sea state and ocean waves which can be provided by spaceborne imaging radar is a very important contribution. This is particularly true for oceans in the Southern Hemisphere where wave measurements in the open ocean are so widely scattered that many areas of the ocean are essentially unknown. Within the Southern Hemisphere oceans at latitudes between 20° and 40°, there is little shipping and almost no land observation points, so the interaction between wind and waves and the

buildup of waves goes on practically unmonitored.

All of this information can be used to generate a global picture of the expected wave spectra or the wave statistics characteristic of these spectra. These data would establish a reference state for the ocean. This state could be considerably more accurate and detailed and with better resolution than the present tabulation by Hogben and Lumb (1967) or those from the U.S. Department of Commerce (1973).

Having a reference condition, continued monitoring of the oceans can be used to reveal any changes that occur due to storms or other large-scale phenomena. These two goals, the development of more accurate global wave statistics and the monitoring of the magnitude of their changes, should be ample justification for the program.

The monitoring of local variations from an established reference condition probably has its most immediate applicability in the routing of ships. The financial benefits obtained by routing ships around areas of heavy seas is quite large and can be easily accomplished with present remote sensing technology. Other advantages would be in the monitoring of large scale storms and their influence, and the tracing of various surface pollutants such as oil spills or the intrusion of salt water into fresh water. Over longer periods,

the compilation of wave statistics and their variation can reveal any unusual or significant changes in topography. In addition, there are a number of specific coastal problems that these data can help resolve.

4.3.2.7 Wave Diffraction and Storm Buildup

Storm surges may be defined as transient anomalies in sea surface elevation (and currents) caused by storms, with time scales in the region 10^4 -10^5 seconds, horizontal scales of order 10^2-10^3km, and vertical excursions up to about 6 m. The associated currents may be regarded as determinable from the gradients of elevation, and will not be considered here as independent variables. Storm surges are largely confined to shelf seas, partly because the dynamic effect of wind stress is inversely proportional to water depth, and also because critical wave speeds in shallow water are comparable with speeds of propagation of weather systems, causing more efficient coupling with the atmosphere than the deep ocean. They have been intensely studied in certain sea areas where they present a frequent danger of flooding to adjacent lowland, as in the southern part of the North Sea, the Adriatic Sea near Venice, and the shelf seas bordering the eastern and southern United States. Flood danger also depends on the coincident state of the tide, and to some extent study of storm surges and local tides are

inseparable.

An important ingredient of some storm surges is a quasi-static pile-up of water towards the coastline, caused by the onshore wind stress and the radiation stress in the associated waves. This effect is usually called wind setup. In some areas, where wind strength and direction persist for many days and coastal topography prevents the formation of steady currents, wind setup may form a steady deformation of sea level of some decimeters. However, although such a setup may not be thought of as a storm surge, its dynamics are not essentially different, and it may be regarded as included in the following discussion.

Imaging radar gives a picture of wave patterns which is at present a qualitative picture of the wave field. Therefore, the fact that waves can be seen makes the imaging radar a powerful tool for the oceanographer mapping wave patterns and wave buildup during large storms. This wave buildup occurs under cloud covers which only active microwave sensors can penetrate. And it is in these large storms that the bigger, more damaging waves are generated.

In addition to mapping storm waves, the mapping of swell over continental shelves will permit the study of wave refraction in coastal regions. The continental shelves are going to be a valuable real estate in the next few decades as

a place to put man's machinery such as off-shore airports, power plants, and oil rigs. The ability to predict wave climates in these areas and to verify these predictions by observations is another important contribution that imaging microwave sensors can make to oceanography. Once again, the ability of active microwave sensors to penetrate clouds during storms is a most important attribute.

When the depth of the water becomes less than half the wavelength of a spectral component in a wave spectrum, the speed of the component is affected by the depth. The shallower the water, the slower the wave travels. Complex offshore submarine topography turns the waves away from deeper regions and focuses them at shallower regions, continental shelves, that are up to several hundred kilometers wide. The depths in these shallow areas are often complex, and the waves are refracted in ways both difficult to describe and to compute.

All structures to be built in such shallow water areas require design wave data so that the structures can withstand the forces on them produced by the high waves during a storm. Also, the continued action of the lower waves can erode away the material around a structure's base and cause it to collapse. With the many proposed offshore structures all around the coasts, the problem of adequate

designs for them will become increasingly more pressing during the next few decades.

4.3.3 Applications Requiring the Special Mode

The applications for which the Special Mode is appropriate include:

- Measurement of soil moisture
- Sea ice monitoring and classification
- Water resources in snow fields
- Mapping of precipitation
- Measurement of atmosphere liquid water content.

In each case, the physical parameter of concern is contained within the material of interest. Therefore, the physical phenomena to be measured in support of the application is not solely an interaction of the transmitted signal with the surface, but relies on interaction of the signal with a volume within the material. The depth of penetration of the transmitted signal is dependent on the signal frequency and the material electrical properties. For applications such as measuring subsurface moisture, snow moisture, and classification of sea ice types, significant volume scatter is only obtained with low frequency microwave signals. Mapping of precipitation and liquid water content can be accomplished with higher signal frequencies. In each case, a need exists to employ multiple radar parameters, usually simultaneously, that is, multiple frequency and/or multiple polarization observations are generally desirable.

4.3.3.1 Soil Moisture Monitoring

Two promising applications for sensing of soil properties are made possible by some of the unique penetration capabilities of microwave systems. Measurement of soil water content would allow the development of a soil moisture index that could be used as input to watershed runoff and crop yield models. Soil moisture monitoring for irrigation requirements has local value and may be accomplished after more precise techniques are developed.

The primary need for soil moisture measurements over large areas stems from a desire to improve prediction models for water resources and crop yield. The spatial distribution of soil moisture indicates that such measurements are feasible with active microwave systems.

Complex continuous watershed models have been developed in past decades to mathematically represent the movement of water in the earth surface portion of the hydrologic cycle. At present, these models are the only means of calculating "low flow" or continuous stream flows. Low flow values for streams and the temporal distribution of flow volumes are extremely important for study of water supplies and the environmental input of changes in a watershed drainage area. Presently, soil moisture input to the models cannot be measured, and are generated by sub-models

based on parameters developed by fitting the overall model to existing watershed data. The use of complex models is thereby restricted to use on watersheds with existing historical records.

Development of a soil moisture index for use as input to crop yield models is likewise very important. Crop yield models are vital to improvement in timely estimates of world food production. Identification and mapping of some major crops is considered feasible. However, no adequate system for measurement of moisture available for the plant root zone has been developed. Laboratory experiments on penetration and soil moisture measurements with microwave systems (Ulaby, 1974) indicate that reasonable estimates of moisture availability for plant growth are feasible.

Other research programs have demonstrated the use of radar measurements from elevated platforms to detect change in soil properties (Lundien, 1966 and 1972; Ulaby, 1974; Ulaby, Cihlar, and Moore, 1973). These efforts have indicated that near-vertical measurements are more desirable than low depression angles because the predominance of the surface roughness comparison of the total radar backscatter is reduced, and the significance of the reflection from vegetation is reduced. Field studies by Morain and Campbell

(1974) confirm these observations. When measurements are made on smooth surfaces at these near vertical angles, the reflectance can be correlated with soil moisture. In addition, when skin depths are significantly large and low frequency results are studied, subsurface composition can be inferred.

The response of microwave energy in soil media is determined by the electrical properties of soil and their spatial distribution. The use of microwave sensors is advancing because of known relations between electrical properties of soils and water content. The electrical conductivity of soils at low frequency is almost exclusively ionic and arises from motion of free or exchangeable ions in the soil solution. Since exchangeable ions often dominate over free ions in solutions, clays are found to have a higher conductivity than coarser grained soils. Typically, the conductivity of soils varies between 10^{-1} mho/m for clay soils to 10^{-3} mho/m for sands and gravel. Because of these high conductivities, conduction currents dominate over displacement currents often to a frequency of about 10^{6} Hz.

Water content influences the conductivity of soils but other factors such as soil and clay types are as important as water content in determining the conductivity of soils. At frequencies above 10^{7} Hz, the influence of conductivity

of soils on the propagation constant begins to diminish and the relaxation of water in soils becomes important.

Increasing the frequency to 10^{10} Hz, causes the relative dielectric constant to decrease significantly over its low frequency value (Hoekstra and Delaney, 1969), as will subjecting the soil to low temperatures.

A transverse electromagnetic wave normally incident on a smooth surface, which has both a finite conductivity and dielectric constant, will be partially reflected at the surface and the remainder will penetrate into the soil. The electric and magnetic fields in the ground will decay exponentially with depth. The skin depth in soil media can have values of up to several meters in the 10^8 Hz to 10^9 Hz frequency range. In the 10^9 Hz to 10^{10} Hz range, the skin depth can shrink to only a few centimeters. Thus, by selecting a number of frequencies for operation, it may be possible to define soil media as a function of depth.

Images produced from side-looking radar systems (SLAR) can be divided into areas of relatively consistent tonal and texture patterns. A relatively few samples from these areas of consistent patterns will serve to identify the physical properties of these areas. Thus, information from a small number of bench-mark stations can be extrapolated to large surface areas. These bench-mark stations

can be entirely composed of ground truth measurements or a limited amount of ground truth supplemented by direct measurements with airborne or truck-mounted radars.

The functional requirements for active microwave systems to measure soil moisture vary considerably with the required ultimate operational system. Three areas of application for soil moisture data are: (1) modeling of watersheds, (2) crop yield predictions, and (3) scheduling of irrigation.

4.3.3.2 Sea Ice Mapping

The polar regions are a fundamental part of the earth's heat engine, yet the way in which they interact with the other parts of the atmosphere-ocean-ice-land system is poorly known because they have existed behind what has been called an "observational barrier". Most polar geophysical studies are based on a paucity of data, relatively short-time series of measurements acquired at a few points spread over vast distances. The state and behavior of the earth's surface is one aspect of the interaction-exchange problem that can be said to be the most important in polar regions, where changes of phase of water into snow and ice occur over large areas at small time scales and where large permanent floating and grounded ice masses are involved in a complex feedback process with atmospheric and oceanic circulation. This

problem can be studied only by using satellite remote sensing techniques.

Of all the forms of frozen water that exist on earth, the one about which least is known is the sea ice that covers vast areas of the oceans; 10% in the northern and 13% in the southern hemisphere. A good example of the paucity of knowledge in this regard is that for the IGY period (International Geophysical Year) essentially nothing is known about the extent and morphology of the winter sea ice surrounding Antarctica.

Individual ice floes have been observed to move 50 km in a day and speeds of 10-20 km a day are common. Leads (cracks) and polynyas (large irregular openings) open and close at all times. The seasonal variations in areal extent of the ice canopies is large; about 15% for the Arctic and 80% for the Antarctic. In short, sea ice is the most rapidly varying solid on the earth's surface.

American radar imaging of the polar sea ice dates back to the early 1960's (Anderson, 1966). In a flight by a military aircraft from the North American continent to the vicinity of the North Pole, a long strip of imagery was obtained with an X-band real-aperture system. The ability of the radar to distinguish various classes and ages of ice was first shown in Anderson's analysis of these

images. In 1967, the NASA Earth Resources Aircraft Program (ERAP) P3A flew north of Point Barrow with the 13.3 GHz scatterometer. By comparing the photographs with ice atlas photographs and information gleaned from conversation with ice observers, Rouse (1969) was able to make tentative identification of ice types and to show that the multi-angle scatterometer observations could be well correlated with ice type.

In 1970, another NASA ERAP mission was mounted north of Point Barrow, with the ice party restricted to the uninteresting fast ice within a few miles of Point Barrow. In this mission, a series of scatterometer lines were flown with both 13.3 GHz and 0.4 GHz instruments; the same area was imaged with the 16.5 GHz DPD-2 multipolarized imaging radar by flying the imager in a box around the area covered by the scatterometer. Parashar, et al. (1974), was able to make excellent identification of ice types by detailed stereoscopic analysis of photographs of the area. The classification by ice type was then converted into effective ice thickness, using the average ice thickness appropriate to each kind of ice. The results were then interpreted in terms of ability to measure ice thickness with the various radars, but most of the work concentrated

on what could be done with individual incident angles appropriate to an imaging radar that might be used operationally.

Indications from image analysis of the DPD-2 were that four categories, open water, ice less than 18 cm thick, ice 18-90 cm thick, and thicker ice, could be readily identified on the images, even though the images were somewhat saturated. This was an indication that the ambiguity in intensity between new ice and meter-thick ice did not exist on the cross-polarized image, but saturation on the film prevented assurance that this conclusion was correct. Parashar, et al. (1974) has also developed a theory that seems to explain the observations.

The Arctic and Antarctic Institute of Leningrad has engaged in imaging of sea ice for at least 6 years (Glushkov and Komarov, 1971). The Soviets believe that they can clearly distinguish thin ice, thick first-year ice, and multiyear ice. In the late spring of 1973, an ice map of the entire shipping region across the north of the Eurasian continent was prepared using the TOROS 16 GHz real aperture radar imager. It is believed that the system is being used operationally in connection with directing shipping convoys along this route. In fact, the Soviet participants in the 1973 joint Bering Sea passive microwave experiment used the

TOROS images for "ground truth" to identify whether the passive microwave was able to distinguish water and ice and one ice type from the other. The Soviets have stated that the radar definitely distinguished more different ice types than did the passive microwave sensors.

4.3.3.3 Snow Cover Measurements

For many drainage basins in the temperate zones of the world, melt waters represent a major part of the annual yield of the basin. In order to properly utilize this water resource and to control flood drainage from high stream discharges during the melt period, hydrologists must have timely information to perform their long and short-term forecasts. Long-term forecasts are important for irrigation, navigation, hydroelectric power, and water supply. These forecasts are usually made on an annual basis. The initial prediction is made at the beginning of the winter season, based on moisture conditions existing in the drainage basin at that time, and the basin response (annual runoff) is projected to various levels of snow accumulation (normal, above normal, below normal) during the winter months. The initial forecasts are revised as additional data on the areal extent of snow cover, depth of cover, and water equivalent become available. This forecasting process continues through the snow melt period, when

additional data become important in determining the volume of melt-water runoff.

The basic objective of the long-term forecast is, therefore, to provide as accurate a prediction of annual runoff from snow melt as possible and with sufficient lead time to provide for maximum utilization of the runoff. This requires accurate monitoring of the snow cover. Specific user agencies would include:

Irrigation	- Irrigation Districts
	- U.S. Department of Agriculture
	- U.S. Bureau of Reclamation
	- State Regulatory Agencies
Hydroelectric Power	- U.S. Army Corps of Engineers
	- U.S. Bureau of Reclamation
	- Bonneville Power Administration
	- Public Power Utilities
	- Private Power Companies
Water Supply	- U.S. Bureau of Reclamation
	- State Regulating Agencies
	- Water Supply Districts
	- Municipalities
Navigation	- U.S. Army Corps of Engineers

Short-term forecasts are primarily involved in flood prediction and assessment of flood-hazard potential. Severe snow melt floods have occurred in the upper Missouri River and Mississippi River basins in 1965 and 1969. Although flood damage was extensive in both instances, good forecasts of the flood potential and advanced planning by federal, state and local authorities served to mitigate the amount of damage. Improved techniques for forecasting could result in even less damage. For flood forecasting purposes, accurate definition of the areal distribution of the snow cover, snow depth and water equivalent of the snow are important, as well as the rate of production of snow melt runoff. The principal federal agencies involved in flood forecasting are the National Weather Service and the U.S. Army Corps of Engineers. At the state and local level, a large number of agencies are involved.

Knowledge of radar return from snow is limited. It is known that old snow gives strong, isotropic returns at 35 GHz, at least in summer. It is also known that 35 GHz snow return in the spring in Quebec is strong enough to obscure the underlying terrain features. Dielectric properties of snow are known. Dry, cold snow has a permittivity close to unity, with low loss. Compacted cold snow has a higher permittivity, but low loss. Snow containing water

in unfrozen form has much higher permittivity and loss. Research by Waite and MacDonald (1970) indicates a feasibility for mapping the extent of old snow cover using K-band imagery, irrespective of most weather conditions. Their work also indicates a significant difference in signal return between old and new snow.

4.3.3.4 Meterological Observations

The most important aspect of radar for meteorological observations is its ability to observe precipitation at distances up to several hundred kilometers, which makes it a true remote sensor for meteorological applications. Ground based weather radar has been found useful mainly for subsynoptic scale, or "mesoscale", observations. They readily provide observations with space continuity impossible to attain with the ordinary synoptic weather reporting network. Such radar observations are of enormous value in a wide variety of applications, including short-term forecasting for local areas or terminal points and many research investigations.

Weather radar observations are of value in forecasting for periods of up to 6 hours. A limiting factor is the variability of precipitation in space and time; the PPI scope of a weather radar set operating during a typical summer afternoon of convective activity reveals a process of continuous

evolution. Cells and storm systems grow and decay; old cells disappear from the scope and new ones form; sometimes cells merge together and less frequently they even split apart. It is even difficult to define a "cell" or "storm" or "echo" in an objective way, although there have been recent developments in this direction (Ostlund, 1974). These conditions greatly inhibit the use of radar observations of precipitation for forecast purposes when extrapolation over appreciable intervals of space or time is required.

Weather radar observations provide a variety of information concerning the precipitation responsible for the echoes. This information can be divided into two categories, according to whether it can be extracted from single "snapshot" observations (as for example, single PPI scans) or whether repetitive observations over an interval of some minutes or hours are required. Such categorization may be helpful in evaluating the potential use of satellites as weather radar platforms, because orbiting satellites provide primarily a "snapshot" capability and to obtain repetitive radar observations in most instances requires operating from geosynchronous satellites or a system of multiple satellites.

The "snapshot" category of information includes the observation of the location, size, and shape of the precipitation regions from two or three dimensional imagery. Also, the precipitation structure can be determined from the pattern of the echoes and the "texture" of individual echo elements and the intensity and intensity gradients from relative or absolute measurements of echo intensity. These characteristics are usually adequate to deduce the basic nature of the precipitation process (for example, stratiform versus convective, air mass versus squall line, etc.). That information, coupled with synoptic information such as environmental wind data and the characteristics of the air mass, can be used to develop short-term forecasts of the future behavior of the precipitation in the area surveyed by the radar. However, the typical rapid evolution of the precipitation restricts the time period of validity of any such forecasts.

Orbiting satellite platforms would provide the potential of a drastic increase of the radar coverage to the synoptic scale, as well as extending observations to the remote oceans and other areas that are not presently covered by any weather radar system. Another advantage of the satellite platform is a possible use of shorter wavelengths since

the radar signals do not have to traverse long paths through rain, thereby reducing the importance of attenuation.

Tropical storms are perhaps the easiest meteorological targets to observe from a satellite. Their size makes them easy to find and their persistence makes it possible to acquire repetitive observations from low-altitude satellites. The fact that they spend most of their lifetimes over water simplifies the technological problems of separating rain-echo signals from surface-echo clutter. Satellite-borne weather radar observations on a once or twice a day return cycle would provide a history of the development and distribution of precipitation within the storms during their entire lifetimes. Such observations are not available from other sensors or other weather radar observations on a once or twice a day return cycle would provide a history of the development and distribution of precipitation within the storms during their entire lifetimes. Such observations are not available from other sensors or other weather radar platforms.

Satellite-borne weather radar observations of tropical storms, especially over the remote oceans, would aid research into the genesis and behavior of such storms

and attempts to develop physical and numberical models describing them. The observing capability could be used to support large-scale research programs such as the GARP Atlantic Tropical Experiment (GATE), the First GARP Global Experiment (FGGE), or Project Stormfury concerned with hurricane modification by silver iodide seeding which is scheduled to be resumed in the Pacific Ocean in 1976. Data from meteorological radars on board orbiting satellites could provide valuable observations for such research efforts. The horizontal distribution or precipitation over the oceans can be obtained from microwave radiometric observations, so any satellite-borne weather radar system should probably be complemented by a radiometer on the same spacecraft with possible use of the same antenna and maybe the same receiver front end for the two systems.

It is proposed that the meteorological information obtainable from a satellite-borne conventional pulse radar would include the global mapping of rainfall intensity, the measurements of storm maximum echo heights, and the measurements of the height of the melting layer which is characterized by a significant increase of radar signal intensity observed mainly in stratispheric precipitation (bright band). Rainfall intensities are now being mapped

over the oceans by the Electrically Scanned Microwave Radiometer (ESMR) installed on Nimbus 5. Thus, the principal value of an active microwave system would be to provide height resolution and thus to allow the three dimensional mapping of precipitation, i.e., inside cyclonic storms. In the absence of a vertical resolution capability, however, the active system provides little advantage over passive radiometric techniques. Over the oceans, radar could probably distinguish rain echoes from sea clutter out to a distance of about 2000 km from nadir from the subsatellite point. This distance is reduced to less than 800 km for precipitation over land.

In the future, satellite weather radar observations may be valuable in providing precipitation distributions for use as input to the numerical weather prediction (NWP) models. The horizontal grid spacing of the present NWP models are basically incompatible with the spatial variations of precipitation as observed by radar, the former being much too large. Partly because of this, the NWP models do not at present use precipitation data as input; in fact, moist convection and precipitation processes are just being incorporated into such models as the Limited Fine Mesh (LFM) model of the National Weather Service.

5.0 Functional Requirements

In this section the functional requirements of the applications identified for each radar mode will be discussed. The list of applications for each radar mode is divided into classes of applications based on the commonality of these functional requirements. Generally, the subgroups have several common system requirements with only one or two requirements being responsible for the subgroupings.

5.1 Functional Requirements of the Radar-Photo Mode

As previously stated, applications requiring an image of the "visible" features of the illuminated scene are those that can be accomplished with the Radar-Photo Mode. These applications are not largely dependent on specific frequencies or polarizations, since the unique capabilities of microwave sensors are not relied upon except for the ability to "see" through inclement weather conditions and/or at night. In addition, the applications are such that the largest possible swath width is desirable and the incident angles are not critical, as long as they are not too near nadir or grazing.

The parameter that separates the applications into two classes is resolution. Crop identification, rangeland

monitoring, lake ice monitoring and land use classification require high resolution and a large number of looks such that high quality imagery is obtained. Photographic quality imagery is required such that the visible features of the illuminated scene can be distinguished. Ice berg identification and monitoring of ship activity compose the second class. The required resolution and number of looks are not as critical for this class, since the radar is essentially operating in a target detection mode.

5.1.1 Class I: Agriculture, Land Use, and Lake Ice

5.1.1.1 Crop Identification and Rangeland Assessment

System requirements for crop identification and rangeland assessment are, for the purposes of this discussion, indistinguishable. One of the primary requirements of these applications are timely and repetitive coverage. There are essentially two types of measurements involved in these applications with each type having a different requirement on timeliness and periodic. These two types of measurements are inventories and crop cover and vigor measurements. It is reported by the Earth/Land Panel of the Active Microwave Workshop that inventories require the least number of measurements, approximately six per growing season, with a tolerable

envelope of two weeks. It is further reported that crop cover and vigor measurements useful in making yield predictions and managerial decisions will require almost real time data with a tolerable envelope of not more than three days.

Resolution is the most critical functional requirement of the radar designed for these applications. The Radar-Photo Mode by its very nature requires high resolution, photographic-like images with a minimum of scintillation. In order to resolve small agricultural systems, a spatial resolution of 15-30 meters will be required. Image gray scale resolution on the order of 1-2 dB should be adequate for a useful image.

Swath width, frequency, polarization, and viewing angles are not critical parameters, but should be maintained within certain limits. Swath width is probably the least critical requirement and as such can be used as an engineering trade-off parameter. It should be as large as possible such that the largest area is covered during each pass. Viewing angle should be within the mid range between 30°-70°. A single wavelength operation in the 1-3 cm range and HH single polarization should be adequate. However, a multi-frequency radar or one with like and cross polarization would

improve the capability for reliable vegetation species identification. K-band radar imagery with HH and HV polarizations has been shown to produce a valid discriminatory tool in studying natural vegetation, while the feasibility for identifying crops has been shown for a combination of Ka, Ku, and X-band imagery.

5.1.1.2 Land Use

As was the case for crop identification and rangeland assessment, timing of data acquisition and dissemination of data to the user are prime factors in the use of remotely sensed data for applications involving land use. Disaster assessment and monitoring is a short term land use application requiring two hours to 10 days coverage, and is the most highly time dependent application. Mid-term applications classified requiring 10-100 days are generally for the purpose of monitoring, updating and regulatory management. Long term applications require data only infrequently but can require that data be acquired at critical periods of the year. The nature of applications such as disaster assessment and regulatory monitoring requires that the overall system have the capability of quick data "turn around". This should be considered an important functional requirement as well as timeliness of data acquisition.

For land use applications, resolution is the dominant system parameter, while frequency, polarization, incident angles and swath width are less critical. Large swath width is desirable, however, this could be sacrificed in order to provide the capability to obtain high quality imagery of high spatial resolution, at least 15 meters. Gray scale resolution of 2 dB is adequate. Although multi-frequency multipolarization is practically always desirable by authors discussing land use in general, it has been shown that a single frequency, single polarization system operating in X or K_u band is adequate for many land use applications.

5.1.1.3 Lake Ice Monitoring

The primary application of lake ice monitoring is for navigational purposes on the Great Lakes and the St. Lawrence River. A five year aircraft program for demonstrating this application is presently in its third year and is quite successful. It has been shown by actual interaction with ship captains that data must be acquired and disseminated within 24 hours. In addition, coverage should be repeated at least every 24 hours.

Actual demonstrations have shown X-band, VV data to be useful for this application. Spatial resolution of 40 meters and a 100 km swath are adequate. Gray scale resolution

of at least 2 dB produces satisfactory images. Incident angles are not critical as long as they are within the mid-range.

5.1.1.4 Class I Functional Requirements

Each of the applications discussed above have very similar functional requirements. They all require a system capable of timely data acquisition and data dissemena-tion. Due to the high spatial resolution requirements of these applications and large number of looks required to provide photographic quality images, the task of data processing for timely data dissemination is complicated by the large amount of data required to generate such images, especially when it is desired to have these images over as large a swath width as possible.

Basic system requirements that are common to each of the applications listed above are:

Frequency	X-band
Polarization	VV or HH
Resolution	15 meters
Swath	100 km
Incident Angles	20°-70°
Grey Scale Resolution	2 dB

These system requirements are not necessarily optimum require-ments for each application, however, they should be adequate for each.

5.1.2 Class II: Ice Berg Detection and Ship Activity

Since ice bergs and ships are not area extensive targets, but approach point targets, a radar designed to image them is essentially being used in the target detection mode. Resolution should be adequate for detection of minimum targets, however, the target will have a higher backscatter cross section than its surroundings, causing the radar image to "bloom" in the area of the target, even for spatial resolutions larger than the dimensions of the target. Resolution on the order of 100 meters will be adequate for these applications.

Frequency, polarization, look angles, and swath width are not critical parameters. A single frequency in the range of L to X-band will be adequate. X-band will probably be the best choice since it will be the least expensive to build. One polarization, probably VV, is satisfactory, mid range look angles and a large swath on the order of 100 km are sufficient. It is apparent that these applications have the same functional requirements as those discussed above in Section 4.1.1, with the exception of resolution.

5.2 Functional Requirements of the Ramage Mode

The applications requiring the Ramage Mode depend upon the proper selection of the radar system parameters in

order to record the phenomena of interest. For these applications, image resolution is generally not the major consideration, and for all the applications listed under this category a Shuttle radar image resolution of 20-50 meters should provide satisfactory data from the user's viewpoint.

The applications appropriate to the Ramage Mode are of these types: Class I - those requiring vegetation penetration primarily; Class II - those requiring surface features enhancement primarily; and Class III - those requiring surface roughness primarily. These applications are:

Class I - Flood mapping, coastal wetlands mapping, soil type mapping

Class II - Landform identification and terrain analysis, petroleum exploration, mineral deposit mapping

Class III - Oil spill detection, global wave climatology, coastal wave processes, wave build-up in storm areas.

5.2.1 Class I Functional Requirements

This class of applications requires that the radar signal penetrate surface vegetation and interact with the upper soil layer to provide information on surface water and soil water. The primary system parameter is wavelength and operation in the 25 cm or longer wavelength region is

considered appropriate. Information on vegetation species is often of assistance in these applications, therefore where practical a 1-3 cm wavelength system operating simultaneously is desirable, but not mandatory. The incident polarization is not critical, but both the like and cross polarized backscattered signals should be recorded. Image resolution in the 30-50 meter range is satisfactory, however quite useful data can be obtained with as poor as 100 meter resolution imagery. In all cases a relatively small incident angle is desired, on the order of 10°-30° from the vertical. Swath width specifications are arbitrary, but 40 km is the narrowest practical swath for satellite imaging for these or any of the following applications.

5.2.2 Class II Functional Requirements

These applications require somewhat more complex system operation than the Class I application, however in general the incident angle is the primary parameter of interest. Surface feature enhancement is particularly important and operation in the incident angle range of 50°-70°. is desired. The mineral deposit mapping application, especially, requires multiple wavelength operation to provide surface composition information over a wide range of structural sizes. Operation at L-band (25cm), X-band (3cm) and

K-band (1cm) is recommended. These wavelengths are also optimum for the other Class II applications. The transmit polarization is not critical, although horizontal polarization may offer some advantages, but both the like and cross polarization backscatter components should be recorded. A resolution in the 20-40 meter range is satisfactory, and as with the Class I applications, a 100 meter resolution image would be useful, especially for petroleum exploration applications. The swath width should be as broad as practical; 100 km is considered a reasonable minimum.

5.2.3 Class III Functional Requirements

These applications utilize the unique interaction of the incident electromagnetic energy with the surface structure. Oil spill detection and global wave climatology depend primarily on small scale wind dependent structure, while the coastal wave processes and wave buildup applications depend on longer gravity dependent waves. Since the wind dependent surface structure have wavelengths of 2 cm or less, a system designed for oil spill detection and/or global wave climatology should operate no lower than Ku-band. In addition, resolution is primarily limited by the size of the oil spills to be detected, therefore resolution of at least 20 meters is desirable. A longer wavelength system

operating between 25-50 cm is applicable to detecting coastal wave processes and wave build-up. Resolution for these applications should be 20-30 meters such that long wave refraction patterns can be resolved on the image.

Incident angles from 20°-50° will be suitable for all Class III applications. A 100 km swath width is adequate. Only like-polarized return information is necessary for long wave imaging, but a cross polarized component may be useful for oil spill detection.

5.3 Functional Requirements of the Special Mode

Applications in the category of Special Mode depend on measurements unique to microwave sensors. For each of these applications, the information of interest is associated with physical parameters contained within the material, therefore, a penetration capability is needed that is not available with visible sensors. These applications will require multiple frequency and/or multipolarization in order to unambiguously make measurements of physical parameters within the volume of interest as a function of depth. The functional requirements of the applications requiring the Special Mode have little commonality. Therefore, the functional requirement of each application will be discussed separately below.

5.3.1 Soil Moisture Mapping and Runoff Prediction

The functional requirements of this application are very similar to those of the Class I Ramage Mode applications. In fact, the primary difference is that at least two frequencies are mandatory for soil moisture mapping. These frequencies should be as low as practial and they should be separated by at least one octave. At the present time, C and L-band are considered the optimum practical frequencies, but L and X-band would be useful if C-band is not available. Low incident angles are required to reduce the interference of vegetation since a vegetation cover must generally be penetrated before the signal interacts with the soil. Dual polarization receiver channels are desirable and a vertically polarized transmit signal may offer some advantages. A swath width of 40 km is probably minimum, but the upper limit of useful swath will be determined by the incident angles required to obtain it. Resolution on the order of 50-100 m has been shown to be useful for run-off prediction based on drainage basin mapping. Finer resolution is not required for soil moisture mapping.

5.3.2 Sea Ice Monitoring

Differentiation of sea ice types has been shown feasible using radar operating in the 2-3 cm wavelength

range. The polarization and incident angles are not critical. That is, based upon existing data it appears that reasonably reliable sea ice mapping can be achieved with a single frequency, single polarization side-looking imaging radar. However, the available data are limited and therefore it is felt that the sea ice monitoring applications should be addressed with at least a dual wavelength, dual polarization (on receive) system. Wavelengths of 1-2 cm and 3-4 cm are recommended. The incident angle should be in the 30°-45° range and maximum achieveable swath width is desired. A resolution of 30-50 meters is adequate. A 30 dB (minimum) dynamic range is required for this application.

5.3.3 Snow Field Mapping

The feasibility of mapping the moisture equivalent of snow fields has not been established. The physical phenomena involved indicates the need for short wavelength microwave sensing and multiple wavelength operation. Dual frequency operation in the 0.5 - 2 cm wavelength range is believed to be satisfactory. Dual polarization (on receive) is desirable. The incident angle is not critical and operation in the 20°-50° range should be satisfactory. Spatial resolution of 15-20 meters is required and amplitude resolution of 1-2 dB is mandatory, with a dynamic range of at least

30 dB. A 20-40 km swath width is satisfactorily if properly positioned.

These specifications are based solely on the expected behavior of the interaction mechanisms, and these are yet to be confirmed by adequate experimental measurements.

5.3.4 Meteorological Observations

This application includes measurements of precipitation, storm intensity, and liquid water content and is the most difficult application to determine suitable system parameters since little is known about radar backscatter obtained while looking down on rain cells. Short, multiple wavelength operation in the 0.5-3.0 cm range is required. An incident angle range beyond 45° is preferred to minimize the ground clutter signal. Single polarization operation is adequate. A 25-30 dB dynamic range with 1-2 dB sensitivity should be satisfactory. A 100 km swath width with a 100 meter spatial resolution is acceptable.

This application requires the use of complementary sensors including a passive microwave radiometer and a ranging system to measure heights of storms. The imaging radar may be a secondary sensor, but insufficient evidence is available at this time to properly formulate the sensor package.

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RESULTS OF THE ACTIVE MICROWAVE WORKSHOP AS RELATED TO IMAGING RADAR

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R. W. Newton and J. W. Rouse, Jr.

INTRODUCTION

As most of you know, the NASA Johnson Space Center conducted an Active Microwave Workshop in Houston, Texas last month at which about 70 experts in the field participated. The objectives of this workshop were to define the applications in each of several discipline areas to which radar sensors could be developed. These discipline areas were addressed in three panels: Earth/Land, Oceans, and Atmosphere. A Technology Support Group was defined in addition to these discipline panels. It was the purpose of the Technology Support Group to supply the discipline panels with information on the present and future state-of-the-art in sensor technology and to make recommendations on the areas of sensor technology that require development in order to meet the sensor requirements imposed by the application areas.

Within the next few minutes, I will provide a summary of the results of this Workshop that apply to imaging radar systems. In this summary, I will describe the application areas that have been identified by the discipline panels. This description will include those that have indicated

potential based upon theoretical relationships but that have yet to be demonstrated. In evaluating these application areas, the AMW participants drew three common conclusions that are important to the Shuttle Imaging Radar Study and that I would like to briefly state before discussing the results of each independent panel. (Slide 1) These basic conclusions are:

1) The majority of applications defined by the discipline panels are applicable to imaging radar systems operated from space platforms. In addition, most of the necessary sensor requirements are feasible with present technology.

2) An aircraft program should be initiated that is devoted to active microwave sensors. These aircraft would serve primarily as an application test bed and would provide data to demonstrate certain theoretically feasible applications for which radar data are presently unavailable.

3) A group of scientists should be identified that would be concerned with the development of a long term microwave program. This group should function as a team to provide continuity to the program and insure that all phases of the program such as sensor development and application demonstration are being addressed.

I will now discuss the results of each panel from which these basic conclusions were drawn. Since I intend to only state the general recommendations and conclusions of each panel, it will be beneficial to review the questions addressed by each panel in arriving at their results. Each panel attempted to answer the following four questions:

1) What information is required in the applications area which can be provided by active microwave sensors that cannot be acquired more economically with other sensors?

2) Does the active microwave sensor serve a complementary, supplementary, or unique role in the particular remote sensing activity?

3) What are the system technical requirements dictated by the application?

4) What experimental research is required to clearly establish the feasibility of active microwave remote sensing in these applications?

Keeping in mind that these are the pertinent questions considered by the panelists, I will now present the results of each panel.

EARTH/LAND

The applications areas considered by the Earth/Land Panel are grouped under the general titles of Vegetation and

Soils; Land Use and Urban Environment; Mineral Resources and Geologic Applications; and Water Resources. It was determined that the imaging radar is the primary sensor of importance since these systems provide two-dimensional data that are required in the broad-area applications identified by the Earth/Land Panel. (Slide 2) Specific applications identified by the Earth/Land Panel for which feasibility is generally accepted are listed on this slide. As you can see these include Lake Ice Monitoring, Flood Mapping, Oil Spill Detection, Landform Identification and Terrain Analysis, Grain Crop Identification, and Broad-Class Land Use Mapping. (Slide 3) Applications for which available research results indicate that the phenomena of interest may be measured satisfactorily with microwave sensors are shown here. These are potential applications for which little data, if any, exist. Before these applications are attempted from space they should be first demonstrated through an aircraft program. (Slide 4A) The first two of the six Earth/Land Panel Recommendations are based upon this idea. The Earth/Land Panelists recommended:

1) That a coordinated interdisciplinary program for the development of active microwave sensing of the earth be initiated,

2) The establishment of ground-based and aircraft experiments to study the characteristics of microwave energy

interaction mechanisms associated with those applications for which theory indicates feasibility but for which little data exists, (Slide 4B)

3) The training of users in the analysis of radar images such that full advantage of the data is taken,

4) The initiation of semi-operational demonstrations for those imaging radar applications that are identified as feasible,

5) The development of a satellite imaging radar experiment using a single or dual wavelength imaging radar system to establish the characteristics or orbital operation on the system and data, and

6) That data analysis be given a high priority in all present and future active microwave programs since in the past the data analysis phase has been neglected by funding agencies.

OCEANS

The Ocean Panelists pointed out that, due to the size of the oceans, conventional studies can only be attempted on a local scale, therefore, the use of active microwave sensing in future aerospace applications programs is vital to ocean studies. Many of the applications of active microwave sensors suggested by the Oceans Panel require the use of

altimeters and/or scatterometers. However, they also indicated that imaging radars are the most versatile instrument for ocean surface observations. Imaging radar applications identified by the Oceans Panel include: (Slide 5)

1) Monitoring of global wave climatology which could be used to plan shipping routes and design ships and offshore platforms,

2) Measuring coastal wave refraction which will provide indications of shoaling,

3) Measuring wave build-up in storm areas,

4) Monitoring ice conditions on the Great Lakes, North Slope, and Polar Regions which will be applicable to weather forecasting, coastal structure design, fishing, and shipping routes.

5) Oil spill detection (Environmental Quality Control), and

6) Observation of ship activities in support of international agreements especially in the "Economic Coastal Zone".

(Slide 6) It should be noted that spaceborne radar systems are essential for almost all of these applications as is indicated by the first of the Ocean Panel's conclusions shown on this slide. Other conclusions of the Oceans Panel are:

2) That it has been difficult to acquire proper oceanic data of important time dependent and short lived ocean events due to the lack of a dedicated oceanic research aircraft,

3) That quantitative relationships between radar signatures and oceanic geophysical parameters have not been firmly established in many cases, primarily due to the lack of sufficient observation,

4) And that development programs of the active microwave sensors for ocean observation appear dispersed with only limited coordination.

As a result of these conclusions, several pertinent recommendations were drawn by the Ocean Panel. (Slide 7) These recommendations were categorized as programmatic and technical. The programmatic recommendations include:

1) Development of an aerospace active microwave systems program dedicated to oceanographic applications. This should include an aircraft program dedicated to the study of oceanographic phenomena,

2) An increase in the research and development of the interpretation of microwave signals returned from sea and ice, and the mathematical modeling of ocean surface phenomena applicable to microwave systems,

3) Initiation of a program for the development of end-to-end data processing for ocean phenomena as detectable by active microwave systems,

4) Exploration of the complementary role of passive sensors,

5) Exploration of Coastal Zone requirements that can be satisfied with active microwave sensors and complementary sensors.

Technical recommendations of particular priority include:

1) The development of a high resolution imaging radar, the requirements of this system would be 10 m resolution and 200 km swath width,

2) The development of digital techniques for handling active microwave data recorded over the oceans.

ATMOSPHERE

In identifying specific applications, the Atmosphere Panel developed an iterative exchange between discipline scientists and radar technologists that were experienced in ground-based weather radar systems and meteorological satellite programs. Ten applications were identified as a result of this exchange, three of which are applicable to imaging radar systems each of which obviously require a spaceborne platform. These three applications are: (Slide 8)

1) To map precipitation intensities over the globe as an input for future numerical models for long range forecasting,

2) To quantitatively measure liquid water content, drop size spectra and rainfall rates on a global scale. This application is also important in short range forecasting of local weather and in flood prediction.

3) To map polar ice cover to measure the atmospheric heat balance in polar regions. This would serve as input to numerical models of the general circulation for weather prediction purposes.

(Slide 9) In addition to these applications, the Atmosphere Panel arrived at four recommendations that are applicable to active microwave systems or programs in general and as such are applicable to imaging systems. They recommended:

1) That a single cohesive research program be established in NASA to develop active microwave techniques to be applied to requirements in the meteorological discipline as well as the oceanographic and earth resources disciplines,

2) That the scientific commonality of certain requirements between two or more disciplines be recognized and emphasized,

3) That the technological commonality of active microwave systems required by the meteorological, oceano-graphic, and earth resources disciplines be studied to achieve maximum cost effectiveness, and

4) That a major allocation of resources be designed for the reduction, validation, analysis, and interpretation of data to be acquired in the flight program. This should include resources for acquisition of ground truth for validating satellite observations.

TECHNOLOGY SUPPORT GROUP

(Slide 10) . The Technology Support Group met with each of the discipline panels during the workshop to determine sensor requirements based on the applications identified. As a result, the Technology Support Group drew several conclusions concerning the status of the required sensor technology.

1) A significant portion of the sensor requirements necessary to meet the Earth/Land and Ocean Panels objectives can be satisfied with a single spaceborne imaging radar system.

2) The performance specifications inferred from most of the application requirements can be met by present day technology,

3) Initial program efforts in developing a radar system include engineering and calibration objectives. Also, it should be understood that the performance of radar can only be assessed under actual flight conditions, and

4) There is an insufficient data base for advancing the theoretical knowledge of the interaction between surface properties and echo characteristics.

(Slide 11) In addition to these conclusions the Technology Support Group made several recommendations. These include:

1) A program should be initiated to develop a spaceborne digital data handling system for preprocessing imaging radar data.

2) A program should be established for the development of lightweight deployable antennas to satisfy stringent swath width and resolution requirements set forth by the discipline panels. It was noted here that if there is an ongoing program in the communications area, it is suggested that a medium for interaction be established.

3) A unified radar sensor development and application program should be developed such that various investigators will have a common source of information. This effort should include an experimental program focused on answering questions relating to near future missions. At least one high altitude aircraft will be needed (50,000 ft.).

4) Instrument development activities should be emphasized and study programs de-emphasized.

CONCLUSION

(Slide 12) In conclusion, I will again state the three basic findings of the Active Microwave Workshop participants. The first is that the applications identified by the discipline panels enforce the need for an orbiting imaging radar system. In addition, the workshop participants felt that the two remaining findings are requirements of a viable long term active microwave program. They felt that it is imperative that an aircraft program be initiated which will provide a means of obtaining basic radar data, that is presently unavailable, in order to demonstrate feasibility of certain theoretically possible applications. It was also generally recommended that a "Radar Team" be identified which would focus and insure the cohesiveness of the microwave program.

COMMON CONCLUSIONS DRAWN BY EACH DISCIPLINE PANEL AND THE TECHNOLOGY SUPPORT GROUP

- THE MAJORITY OF APPLICATIONS DEFINED DURING THE ACTIVE MICROWAVE WORKSHOP ARE APPLICABLE TO IMAGING RADAR SENSORS

- AN AIRCRAFT EXPERIMENTAL PROGRAM SHOULD BE INITIATED THAT IS DEVOTED TO ACTIVE MICROWAVE SENSORS

- A RADAR TEAM SHOULD BE IDENTIFIED THAT WOULD BE CONCERNED WITH THE DEVELOPMENT OF A LONG TERM ACTIVE MICROWAVE PROGRAM

THOSE AREAS IDENTIFIED BY THE EARTH/LAND PANEL FOR WHICH FEASIBILITY IS GENERALLY ACCEPTED INCLUDE:

- LAKE ICE MONITORING
- FLOOD MAPPING
- OIL SPILL DETECTION
- LANDFORM IDENTIFICATION AND TERRAIN ANALYSIS
- GRAIN CROP IDENTIFICATION
- BROAD-CLASS LAND USE MAPPING

EARTH/LAND APPLICATIONS FOR WHICH AVAILABLE RESEARCH RESULTS INDICATE THAT THE PHENOMENA OF INTEREST MAY BE MEASURED SATISFACTORILY WITH MICROWAVE SENSORS INCLUDE:

- SOIL MOISTURE DETERMINATION
- SOIL TYPE MAPPING
- PETROLEUM EXPLORATION
- RANGELAND INVENTORIES
- CROP CONDITION AND BIOMASS ESTIMATES
- MINERAL DEPOSIT MAPPING
- COASTAL WETLANDS MAPPING
- SNOW FIELD MAPPING

EARTH/LAND PANEL RECOMMENDATIONS

1. PROGRAM DEVELOPMENT - INITIATE A COORDINATED INTERDISCIPLINARY PROGRAM FOR DEVELOPMENT OF ACTIVE MICROWAVE SENSING OF THE EARTH

2. MEASUREMENTS - ESTABLISH MULTI-FREQUENCY, MULTI-POLARIZATION, GROUND-BASED AND AIRCRAFT EXPERIMENTS AND MODEL DEVELOPMENT TO STUDY THE CHARACTERISTICS OF MICROWAVE ENERGY INTERACTION MECHANISMS ASSOCIATED WITH MEASUREMENTS OF:

   A. SOIL MOISTURE
   B. SURFICIAL MATERIALS
   C. VEGETATION PENETRATION
   D. CROP MOISTURE EFFECT
   E. VEGETATION SPECIES
   F. SNOW MOISTURE CONTENT
   G. FROZEN GROUND
   H. OTHERS

3. INTERPRETATION - TRAIN WIDE RANGE OF USERS IN INTERPRETATION OF RADAR IMAGES TO TAKE ADVANTAGE OF UNIQUENESS AND FULL-TIME OPERATIONAL CAPABILITY. DEVELOP IMAGE INTERPRETATION METHODOLOGY FOR USE WITH SLAR.

4. OPERATIONAL TESTS - CONDUCT SEMI-OPERATIONAL DEMONSTRATIONS FOR THOSE IMAGING RADAR APPLICATIONS IDENTIFIED AS FEASIBLE, POTENTIALLY USEFUL, AND CAPITALIZE ON THE UNIQUE CHARACTERISTICS OF RADAR.

5. SATELLITE EXPERIMENT - CONDUCT A SATELLITE IMAGING RADAR EXPERIMENT USING A SINGLE OR DUAL WAVELENGTH IMAGING RADAR SYSTEM TO ESTABLISH THE CHARACTERISTICS OF ORBITAL OPERATION ON THE SYSTEM AND THE RADAR DATA.

6. DATA ANALYSIS - IT IS RECOMMENDED THAT DATA ANALYSIS AND INTERPRETATION TECHNIQUES BE GIVEN A HIGH PRIORITY IN ALL PRESENT AND FUTURE ACTIVE MICROWAVE PROGRAMS.

IMAGING RADAR APPLICATIONS IDENTIFIED BY THE OCEAN PANEL

- GLOBAL WAVE CLIMATOLOGY
- COASTAL WAVE DIFFRACTION
- WAVE BUILD-UP IN STORM AREAS
- MONITORING OF ICE CONDITIONS
- ENVIRONMENTAL QUALITY CONTROL
- OBSERVATIONS OF SHIP ACTIVITIES IN SUPPORT OF INTERNATIONAL AGREEMENTS, ESPECIALLY IN THE ECONOMIC COASTAL ZONE

OCEAN PANEL CONCLUSIONS

1. SPACEBORNE ACTIVE MICROWAVE SYSTEMS CAN BEST PROVIDE DATA FOR:

   A. WAVE HEIGHT SPECTRA
   B. WAVE DIFFRACTION
   C. DISTRIBUTION OF SEA AND LAKE ICE

2. ADEQUATE MICROWAVE OCEANIC DATA HAS NOT BEEN ACQUIRED DUE TO THE LACK OF A DEDICATED RESEARCH AIRCRAFT

3. QUANTITATIVE RELATIONSHIPS BETWEEN RADAR SIGNATURES AND OCEANOGRAPHIC PARAMETERS HAVE NOT BEEN FIRMLY ESTABLISHED DUE TO LACK OF OBSERVATIONS

4. PROGRAMS FOR THE DEVELOPMENT OF ACTIVE MICRO-WAVE SENSORS FOR OCEAN OBSERVATION HAVE BEEN DISPERSE WITH LIMITED COORDINATION

OCEAN PANEL RECOMMENDATIONS

PROGRAMMATIC

- DEVELOP A COORDINATED PROGRAM FOR ACTIVE MICROWAVE REMOTE SENSING OF OCEAN PHENOMENA
- INCREASE EMPHASIS ON THE DEVELOPMENT OF:
  - DATA INTERPRETATION
  - MATHEMATICAL MODELING OF OCEAN SURFACE PHENOMENA
- INITIATE PROGRAM IN THE DEVELOPMENT OF DATA PROCESSING TECHNIQUES
- EXPLORE PASSIVE SENSORS AS COMPLEMENTARY SENSORS.
- EXPLORE COASTAL ZONE REQUIREMENTS

TECHNICAL

- DEVELOP HIGH RESOLUTION IMAGING RADAR
  - 10 M RESOLUTION
  - 200 KM SWATH
- DEVELOP DIGITAL DATA HANDLING TECHNIQUES

ATMOSPHERE PANEL APPLICATIONS PERTINENT TO IMAGING RADAR SYSTEMS

- MAP PRECIPITATION INTENSITY
- MAP LIQUID WATER CONTENT AND DROP SIZE SPECTRA
- MAP POLAR SEA ICE COVER

ATMOSPHERE PANEL RECOMMENDATIONS

1. ESTABLISH A SINGLE COHESIVE RESEARCH PROGRAM TO DEVELOP ACTIVE MICROWAVE TECHNIQUES IN ALL THREE DISCIPLINE AREAS

2. RECOGNIZE AND EMPHASIZE SCIENTIFIC COMMONALITY OF REQUIREMENTS BETWEEN DISCIPLINES

3. STUDY TECHNOLOGICAL COMMONALITY TO ACHIEVE MAXIMUM COST EFFECTIVENESS

4. ALLOCATE A MAJOR PERCENTAGE OF RESOURCES FOR DATA REDUCTION, VALIDATION, AND ANALYSIS

TECHNOLOGY SUPPORT GROUP CONCLUSIONS

1. A SINGLE SPACEBORNE IMAGING RADAR CAN SATISFY MOST OF THE EARTH/LAND AND OCEAN APPLICATION OBJECTIVES

2. PRESENT DAY TECHNOLOGY IS SUITABLE FOR MOST SENSOR REQUIREMENTS

3. RADAR PERFORMANCE CAN ONLY BE ASSESSED UNDER ACTUAL FLIGHT CONDITIONS

4. THERE IS AN INSUFFICIENT BASE OF RADAR DATA PERTINENT TO MANY APPLICATION AREAS

TECHNOLOGY SUPPORT GROUP RECOMMENDATIONS

1. ON BOARD DIGITAL DATA HANDLING SYSTEMS NEED TO BE DEVELOPED

2. LIGHTWEIGHT DEPLOYABLE ANTENNAS NECESSARY TO MEET STRINGENT RESOLUTION REQUIREMENTS NEED TO BE DEVELOPED

3. A RADAR SENSOR DEVELOPMENT AND APPLICATION PROGRAM SHOULD BE INITIATED

4. INSTRUMENT DEVELOPMENT PROGRAMS SHOULD BE EMPHASIZED AND STUDY PROGRAMS DE-EMPHASIZED